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Estimation of Heterosis, Inbreeding Depression and Combining Ability by Using Diallel Analysis in F1 and F2 Generations for Some Quantitative Traits in Egyptian Cotton

M. W. El-Shazly[1], A. H. Mabrouk[1], A. M. Soliman[1] and Manal M. Zaater[2]

[1]Cotton Research Institute, Agricultural Research Center, Egypt.
[2]Agricultural Biotechnology Department, Faculty of Agriculture, Damietta University, Egypt.

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ABSTRACT

Plant breeders are seeking for desired genes and gene combinations, therefore identifying prospective individuals is critical in any breeding program. In this trend, this study was conducted at Sakha Agricultural Research Station, Cotton Research Institute, Egypt, during three growing seasons (2021 to 2023). Six Egyptian cotton varieties were used, using diallel analysis in F_1 and F_2 generations. Genotypes, parents, crosses, and parents vs. crosses mean squares were extremely significant for all the studied characters in both generations, except for uniformity index in F_2 generation for parents versus crosses. Giza 86 and Giza 94 exhibited significant desirable GCA effects for most yield traits in both generations, while Giza 92 and Giza 96 for most fiber quality traits in both generations. The crosses (Giza 96 x Giza 97) followed by (Giza 86 x Giza 92) were significant and positive (desirable) SCA effects for most yield and fiber quality properties in both generations. The cross combinations (Giza 85 x Giza 86), (Giza 85 x Giza 92), (Giza 85 x Giza 94), (Giza 85 x Giza 96), (Giza 86 x Giza 96), (Giza 94 x Giza 96) and (Giza 96 x Giza 97) demonstrated the best heterosis over mid and better parents for most studied traits in F_1. The results indicated that the additive genetic variance was higher as compared with non-additive genetic variance in both F_1 and F_2 for B/P, SCY/P, LCY/P and PI in both F_1 and F_2, indicating that additive effects play a major role in the expression of these traits.

Keywords: Cotton, Diallel analysis, Combining ability, Heterosis

1. Introduction

Plant breeders are seeking for desired genes and gene combinations, therefore identifying prospective individuals is critical in any breeding program. Diallel mating design is one of those methods that breeders use to find possible genotypes and promising recombinants created by merging the parental individuals via GCA and SCA. Diallel mating involves crossing the parents in all conceivable combinations to determine the best/poor general combiners via GCA and the cross combinations through SCA.

On the contrary, Ekinci and Basbag (2018) significant GCA effects were be found for all studied traits indicating the importance of additive gene effects. Significant SCA effects were found for fiber fineness, highlighting the importance of non-additive gene effects controlling in the inheritance of the traits. Moreover, Chaudhary *et al*., (2019) The genotype NIAB-KIRN was discovered to have additive gene action for seed index, and seed cotton yield, and it proved to be an excellent general combiner. The cross PB-896 × PB-76 demonstrated high specific combiner for seed cotton yield, indicating the significance of non-additive gene effects for these traits.

Abro *et al*. (2021) indicated that line CRIS-342 and the tester variety NIA-Noori were the best general combiners. Specific combining ability with dominant gene effects in the cross (CRIS-342 × NIA-Noori) demonstrated the potential for increasing the number of bolls/plant, boll weight, and seed cotton yield/plant. Further, Gnanasekaran and Thiyagu (2021) indicated that all studied traits were greater SCA variance as compared than GCA, indicating the predominance of dominant gene action.

Corresponding Author: Mohab Wagdy El-Shazly, Cotton Research Institute, Agricultural Research Center, Egypt. E-mail: mohab_elshazly2016@yahoo.com; mohab.elshazly@arc.sci.eg

Two parents were identified as having high GCA for seed cotton yield and should be used to generate hybrids or recombinants. Three hybrids were chosen as the best for seed cotton yield, one for fiber qualities, and both were suggested for heterosis breeding. Furthermore, Moiana *et al*. (2021) reported predominance of non-additive effects for all the studied characters.

Abou-Ghaneima *et al.* (2023) six Egyptian cotton varieties were employed in half diallel proportions. The results revealed that SCA variances were greater than GCA variances for all studied traits except L%, demonstrating the predominant role of non-additive genetic variance in the inheritance of these traits.

Abd El Samad *et al,* (2023) six cotton genotypes were crossed to produce 15 F_1 crosses, followed by F_2. The results revealed that additive as well as dominance variance values were significant for all the studied traits, with additive values being fewer than dominance values, indicating the importance of dominance variance in inheritance of studied traits.

The combination of PB-896 and FH-942 resulted in considerable heterosis in fiber and seed cotton yield, Al-Hibbiny *et al.* (2020) and Mokadem *et al*. (2020) found highly significant and desirable heterosis relative to mid as well as better parents, Mabrouk *et al.,* (2018) the following crosses, (Giza 70 x Giza 86), (Giza 70 x Australy 13), and (Australy 13 x Pima S4), revealed best heterosis relative to mid as well as better parents for some yield traits, whilst Giza 70 x Giza 92 as well Giza 70 x Giza 86 showed best heterosis relative to mid parent for uniformity ratio. The findings revealed that non-additive genetic variations were larger than additive genetic variance for all studied traits, except lint percentage, fiber length, and fiber strength characters.

This study was conducted to estimated heterosis, combining ability, gene action, inbreeding depression for yield and its components and fiber properties among six parents and their fifteen cotton crosses in the F_1 and F_2 generations.

2. Materials and Methods

2.1. Genetic materials and experimental procedures:

This study was carried out at Sakha Agricultural Research Station Kafr El-Sheikh Governorate, Egypt. Two groups of material were evaluated, viz. parents and F_1' s (group 1); and parents and F_2' s (group 2) during 2021 to 2023 growing seasons. Genotypes included six Egyptian cotton varieties i.e, Giza 85, Giza 86, Giza 92, Giza 94 Giza 96 and Giza 97. The mating design used for this experiment was half diallel. In 2021 growing season, the parents were hand crossed to form 15 F_1 crosses. Hybrid seeds of the 15 F_1 crosses were planted and self-pollination was done to produce 15 F_2 seeds during 2022 growing season.

Selfed seeds of the six parents as well as their 15 F_1 and F_2 crosses were evaluated during 2023 growing season in a randomized complete blocks design (RCBD) with three replicates. Each replicate consisted of three ridges for both parents and F_1 and four ridges for F_2 crosses. Experimental plot consisted of one raw of 4.0 m in length and 0.6 m in width. Seeds were planted in hills spaced 40 cm apart and one plant was left per hill at thinning time. The experiment received the recommended agronomic treatments of the commercial area. Pedigree and category of six Egyptian cotton varieties are presented in Table (1).

Table 1: Pedigree and category of the six Egyptian cotton varieties used in this study.

No.	Variety	Pedigree	Category
P_1	**Giza 85**	Giza 67 x CB 58	Long staple
P_2	**Giza 86**	Giza 75 x Giza 81	Long staple
P_3	**Giza 92**	Giza 84 x (Giza 74 x Giza 68)	Extra-long
P_4	**Giza 94**	10229 x Giza 86	Long staple
P_5	**Giza 96**	(Giza 84 x (Giza 70 x Giza 51b)) x S62	Extra-long
P_6	**Giza 97**	[(Giza 89 x A 101) x Giza 86] x Giza 94	Long staple

The studied characters were:

- Seed cotton yield (g) / plant (SCY/P)
- Bolls / plant (B/P).
- Boll weight (g) (BW)
- 2.5% span length (mm) (2.5% SL) (mm)
- Micronaire reading (MR)
- Lint cotton yield (g) / plant (LCY/P)
- Lint percentage (L %)
- Seed index (g) (SI)
- Pressley index (PI)
- Uniformity index (UI)

All fiber properties were measured in Cotton Technology Research Division's Laboratories at Cotton Research Institute, Agricultural Research Center (ARC), Giza, Egypt.

2.2 Statistical and genetic procedures

The recorded data were subjected to analysis of variance technique (Steel and Torrie, 1980) to obtain level of significance of difference among the genotypes, crosses, parents and parents vs. crosses. In addition, the mean values of parents and crosses were utilized to estimate heterosis over mid (MP) and better parents (BP), as described by Matzinger *et al.* (1962) and Fonseca and Patterson (1968). Griffing's Method 2 Model 1 (fixed model) (Griffing, 1956) was used to estimate general combining ability (GCA) for the six parents and specific combining ability (SCA) for their hybrids for the traits with significant genotypic variances.

3. Results and Discussion

3.1. Analysis of variance

The analysis of variance revealed that differences among genotypes, parents, crosses and parents versus crosses were statistically significant for all the studied traits, except UI in group 2 for parents versus crosses indicating presence of considerable amount of genetic variability (Table 2). Similar results were reported by El-Dahan *et al.* (2006), Swetha *et al*. (2018) and Yehia and El-Hashash (2019).

Table 2: Mean square estimates for the studied characters in parents, F_1 and F_2 generations.

S.O.V.	d.f.	Group	SCY/P (g)	LCY/P (g)	B/P	L %	BW (g)
Replications	2	1	57.50	2.03	5.58	0.66	0.001
		2	22.00	6.60	10.79	0.31	0.02
Genotypes	20	1	3286.99**	599.46**	249.72**	4.21**	0.13**
		2	3637.75**	674.71**	305.33**	4.48**	0.08**
Parents (P)	5		4852.76**	915.77**	387.83**	8.45**	0.10**
Crosses (C)	14	1	2531.80**	434.57**	214.02**	1.82**	0.08**
		2	3131.35**	557.80**	283.99**	1.74**	0.06**
P *VS.* C	1	1	6030.76**	1326.26**	58.92**	16.41**	0.96**
		2	4652.29**	1106.10**	191.68**	22.89**	0.20**
Error	40	1	32.08	6.92	4.09	0.35	0.003
		2	43.24	9.14	4.71	0.42	0.01

*and** Significant at 0.05 and 0.01 levels of probability, respectively.

Table 2: Continued.

S.O.V.	d.f.	Group	SI (g)	2.5% SL (mm)	PI	MR	UI
Replications	2	1	0.21	0.11	0.001	0.02	0.15
		2	0.01	0.09	0.05	0.04	0.02
Genotypes	20	1	0.45**	3.56**	0.34**	0.30**	1.64**
		2	0.55**	3.17**	0.29**	0.29**	1.63**
Parents (P)	5		0.48**	5.45**	0.42**	0.42**	2.36**
Crosses (C)	14	1	0.41**	2.12**	0.26**	0.23**	1.02**
		2	0.57**	1.73**	0.26**	0.20**	0.48**
P *VS.* C	1	1	0.88**	14.18**	1.11**	0.77**	6.64**
		2	0.64**	11.93**	0.08**	0.95**	14.06
Error	40	1	0.04	0.05	0.01	0.02	0.31
		2	0.02	0.06	0.01	0.01	0.31

*and** Significant at 0.05 and 0.01 levels of probability, respectively.

3.2. Combining ability analysis

The analysis of variance of the diallel (Table 3) indicated that general combining ability (GCA) for six parents was highly significant for all studied traits in both group 1 and 2. This indicates that at least one parent was superior to the others, regarding the mean performance in hybrid combinations. For SCA, significant effects were found for all studied traits in both groups 1 and 2, which indicates that the hybrid combinations differed from each other. Similar results were reported by Swetha *et al.* (2018), Balcha *et al.* (2019), Yehia and El-Hashash (2019) and Max *et al.* (2021).

Table 3: Mean square estimates for the studied characters for combining abilities in F_1 and F_2 generations.

S.O.V.	d.f.	Group	SCY/P (g)	LCY/P (g)	B/P	L %	BW (g)
GCA	5	1	3844.80**	680.36**	308.71**	2.78**	0.09**
		2	4214.08**	768.18**	348.25**	2.46**	0.07**
SCA	15	1	179.28**	39.64**	8.08**	0.95**	0.03**
		2	212.08**	43.81**	19.62**	1.17**	0.01**
Error	40	1	10.69	2.31	1.36	0.12	0.001
		2	14.41	3.05	1.57	0.14	0.002

*and** Significant at 0.05 and 0.01 levels of probability, respectively.

Table 3: Continued.

S.O.V.	d.f.	Group	SI (g)	2.5% SL (mm)	PI	MR	UI
GCA	5	1	0.32**	2.89**	0.31**	0.24**	1.00**
		2	0.55**	2.65**	0.31**	0.24**	0.87**
SCA	15	1	0.09**	0.62**	0.05**	0.05**	0.39**
		2	0.06**	0.53**	0.03**	0.05**	0.44**
Error	40	1	0.01	0.02	0.005	0.01	0.10
		2	0.01	0.02	0.01	0.004	0.10

*and** Significant at 0.05 and 0.01 levels of probability, respectively.

3.3. The mean performance of genotypes

Mean performances due to parents, F_1 hybrids as well as F_2 populationsfor yield and fiber quality properties are presented in Table (4). Results revealed that parent Giza 86 was the best means for BW, SI and UI. On the other side, the crosses Giza 86 × Giza 96 showed best mean performances for BW in F_1 generation while, Giza 86 × Giza 92 indicated best mean performances for UI in both generations. On the other hand, the cross Giza 86 × Giza 96 gave the best means for SI in both generations. The highest mean performance was found for the parent Giza 92 for MR, and the cross Giza 92 × Giza 94 showed the highest mean performance for MR in F_2 generation. Parent Giza 94 was the best means for L%, also the cross Giza 94 × Giza 97 showed the highest mean performance for L% in F_1. Likewise, Giza 96 for B/P, SCY/P, LCY/P, 2.5% SL and PI, the cross Giza 96 × Giza 97 showed the highest mean performance for B/P in F_2 generation and PI in both generations, Giza 92 × Giza 96 gave the best means for 2.5% SL in F_1, while the cross Giza 94 × Giza 96 showed the highest mean performance for SCY/P and LCY/P in both generations.

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Table 4: Mean performances for the studied characters for parents and their crosses in F_1 and F_2 generations.

Genotypes		SCY/P (g)	LCY/P (g)	B/P	L %	BW (g)
Giza 85		167.03	62.76	54.05	37.58	3.09
Giza 86		187.77	75.24	53.07	39.42	3.54
Giza 92		140.13	50.60	45.16	36.13	3.10
Giza 94		204.90	84.85	60.23	40.73	3.40
Giza 96		234.60	92.21	72.43	38.80	3.24
Giza 97		127.83	51.08	40.25	39.97	3.18
Giza 85 x Giza 86	**F_1**	197.33	78.60	53.30	39.83	3.70
	F_2	178.13	72.80	49.49	40.87	3.60
Giza 85 x Giza 92	**F_1**	173.27	67.91	51.92	39.20	3.34
	F_2	160.13	62.89	49.12	39.27	3.27
Giza 85 x Giza 94	**F_1**	212.37	85.36	61.45	40.20	3.46
	F_2	197.47	81.03	61.76	41.03	3.20
Giza 85 x Giza 96	**F_1**	225.53	88.33	69.12	39.17	3.26
	F_2	235.27	94.44	71.29	40.13	3.30
Giza 85 x Giza 97	**F_1**	157.80	63.54	46.59	40.27	3.39
	F_2	163.73	64.28	49.60	39.27	3.30
Giza 86 x Giza 92	**F_1**	186.43	75.01	51.09	40.23	3.65
	F_2	174.47	70.98	48.52	40.70	3.60
Giza 86 x Giza 94	**F_1**	206.97	84.44	55.78	40.80	3.71
	F_2	206.63	84.65	57.95	40.97	3.57
Giza 86 x Giza 96	**F_1**	242.67	95.69	64.60	39.43	3.76
	F_2	232.60	93.53	65.26	40.20	3.57
Giza 86 x Giza 97	**F_1**	187.93	76.74	51.23	40.83	3.67
	F_2	176.50	70.83	53.00	40.13	3.33
Giza 92 x Giza 94	**F_1**	186.93	73.46	51.40	39.30	3.64
	F_2	191.77	75.69	55.84	39.47	3.43
Giza 92 x Giza 96	**F_1**	219.30	88.37	67.48	40.30	3.25
	F_2	222.77	87.68	66.19	39.37	3.37
Giza 92 x Giza 97	**F_1**	141.93	55.18	40.64	38.87	3.49
	F_2	136.20	53.80	41.33	39.50	3.30
Giza 94 x Giza 96	**F_1**	245.43	100.63	67.83	41.00	3.62
	F_2	244.77	100.20	71.29	40.93	3.43
Giza 94 x Giza 97	**F_1**	185.10	75.17	52.06	40.60	3.56
	F_2	187.60	72.91	57.44	38.87	3.27
Giza 96 x Giza 97	**F_1**	211.53	85.80	60.57	38.50	3.49
	F_2	232.97	95.29	72.79	40.90	3.20
$LSD_{0.05}$	**F_1**	**2.13**	**0.99**	**0.76**	**0.22**	**0.02**
	F_2	**2.48**	**1.14**	**0.82**	**0.24**	**0.03**
$LSD_{0.01}$	**F_1**	**2.85**	**1.32**	**1.02**	**0.30**	**0.03**
	F_2	**3.31**	**1.52**	**1.09**	**0.33**	**0.04**

Table 4: Continued.

Genotypes		SI (g)	2.5% SL (mm)	PI	MR	UI
Giza 85		10.33	31.97	10.17	4.10	84.47
Giza 86		10.63	34.33	10.53	4.30	86.90
Giza 92		10.00	35.50	10.83	3.37	86.30
Giza 94		10.07	34.73	10.17	4.30	86.07
Giza 96		9.67	35.57	11.10	3.67	85.17
Giza 97		9.57	33.67	10.40	4.03	85.27
Giza 85 x Giza 86	**F_1**	10.65	34.70	10.77	3.96	87.23
	F_2	10.87	34.80	10.55	3.58	87.17
Giza 85 x Giza 92	**F_1**	10.95	36.00	11.10	3.27	86.87
	F_2	10.30	35.80	10.88	3.45	86.83
Giza 85 x Giza 94	**F_1**	10.32	34.97	10.27	3.90	86.97
	F_2	10.10	35.03	10.05	3.72	86.53
Giza 85 x Giza 96	**F_1**	10.38	36.30	11.20	4.09	86.07
	F_2	10.07	35.83	10.98	3.85	86.10
Giza 85 x Giza 97	**F_1**	9.98	33.83	10.57	3.39	86.13
	F_2	9.83	33.73	10.35	3.92	86.40
Giza 86 x Giza 92	**F_1**	9.88	35.90	11.00	3.43	87.30
	F_2	10.87	36.10	10.78	3.45	87.20
Giza 86 x Giza 94	**F_1**	10.65	34.70	10.67	3.93	86.80
	F_2	10.60	35.67	10.45	3.75	86.93
Giza 86 x Giza 96	**F_1**	10.95	36.20	11.13	3.60	85.83
	F_2	11.03	35.83	10.92	3.85	87.20
Giza 86 x Giza 97	**F_1**	10.32	33.97	10.60	4.00	85.80
	F_2	10.68	34.10	10.38	3.78	86.60
Giza 92 x Giza 94	**F_1**	10.38	35.47	10.70	3.43	87.20
	F_2	10.13	35.27	10.48	3.18	87.13
Giza 92 x Giza 96	**F_1**	9.98	36.47	10.97	3.43	85.93
	F_2	9.77	35.87	10.75	3.35	86.70
Giza 92 x Giza 97	**F_1**	9.88	35.03	10.90	3.66	86.00
	F_2	9.83	34.90	10.68	3.50	86.00
Giza 94 x Giza 96	**F_1**	10.38	35.77	10.80	3.85	86.37
	F_2	10.23	36.40	10.58	3.88	87.20
Giza 94 x Giza 97	**F_1**	9.98	34.80	10.43	4.05	85.63
	F_2	9.83	34.63	10.22	4.10	86.43
Giza 96 x Giza 97	**F_1**	9.88	36.07	11.30	3.74	86.07
	F_2	9.87	34.90	11.08	3.97	86.67
$LSD_{0.05}$	**F_1**	**0.07**	**0.09**	**0.04**	**0.05**	**0.21**
	F_2	**0.06**	**0.09**	**0.04**	**0.04**	**0.21**
$LSD_{0.01}$	**F_1**	**0.10**	**0.11**	**0.06**	**0.06**	**0.28**
	F_2	**0.08**	**0.12**	**0.06**	**0.05**	**0.28**

3.4 Combining ability effects

General combining ability effects (GCA) of parental genotypes for the studied characters in F_1 and F_2 generations are shown in Table (5). The results indicated that Giza 85 showed positive and significant GCA effects for SI in group 1. Giza 86 and Giza 94 presented the greatest yield and yield components in relation to the other parents in both 1 and 2 groups.

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Table 5: General combining ability effects of parental genotypes for the studied characters in F_1 and F_2 generations.

Genotypes	Group	SCY/P (g)	LCY/P (g)	B/P	L %	BW (g)
Giza 85	1	-5.90**	-3.47**	0.05	-0.40**	-0.11**
	2	-8.20**	-3.95**	-1.17**	-0.29*	-0.07**
Giza 86	1	6.16**	3.00**	-0.99**	0.37**	0.17**
	2	1.18	1.34*	-2.29**	0.45**	0.16**
Giza 92	1	-19.93**	-9.48**	-4.65**	-0.86**	-0.08**
	2	-21.10**	-10.04**	-5.92**	-0.94**	-0.03**
Giza 94	1	12.38**	6.47**	2.36**	0.79**	0.08**
	2	12.95**	6.45**	3.26**	0.58**	0.03*
Giza 96	1	33.26**	13.28**	10.55**	-0.13	-0.04**
	2	37.89**	15.37**	11.62**	0.13	-0.01
Giza 97	1	-25.95**	-9.80**	-7.31**	0.24*	-0.03*
	2	-22.72**	-9.16	-5.50**	0.07	-0.08**
$LSD_{0.05}$	**1**	**2.13**	**0.99**	**0.76**	**0.22**	**0.02**
	2	**2.48**	**1.14**	**0.82**	**0.24**	**0.03**
$LSD_{0.01}$	**1**	**2.85**	**1.32**	**1.02**	**0.30**	**0.03**
	2	**3.31**	**1.52**	**1.09**	**0.33**	**0.04**

*and** Significant at 0.05 and 0.01 levels of probability, respectively.

Table 5: Continued.

Genotypes	Group	SI (g)	2.5% SL (mm)	PI	MR	UI
Giza 85	1	0.17**	-0.70**	-0.12**	0.04	-0.16
	2	0.05	-0.72**	-0.12**	0.04**	-0.39**
Giza 86	1	0.26**	-0.15**	0.004	0.13**	0.41**
	2	0.49**	0.04	0.004	0.08**	0.48**
Giza 92	1	-0.07*	0.57**	0.14**	-0.32**	0.31**
	2	-0.07*	0.51**	0.14**	-0.34**	0.17
Giza 94	1	0.03	-0.02	-0.25**	0.16**	0.21*
	2	-0.05	0.20**	-0.25**	0.11**	0.16
Giza 96	1	-0.09*	0.83**	0.30**	-0.06*	-0.36**
	2	-0.14**	0.64**	0.30**	-0.02**	-0.11
Giza 97	1	-0.30**	-0.53**	-0.07**	0.05*	-0.41**
	2	-0.28**	-0.66**	-0.07**	0.12**	-0.31**
$LSD_{0.05}$	**1**	**0.07**	**0.09**	**0.04**	**0.05**	**0.21**
	2	**0.06**	**0.09**	**0.04**	**0.04**	**0.21**
$LSD_{0.01}$	**1**	**0.10**	**0.11**	**0.06**	**0.06**	**0.28**
	2	**0.08**	**0.12**	**0.06**	**0.05**	**0.28**

*and** Significant at 0.05 and 0.01 levels of probability, respectively.

These results revealed that Giza 86 and Giza 94 might be recommended as the best combiners to improve yield and yield components. Also, Giza 92 gave desirable effects for all fiber traits in both 1 and 2 groups. Concering, Giza 96, GCA effects were significant desirable for SCY/P, LCY/P, B/P, 2.5% SL, PI and MR in both groups. This variety proved to be an excellent combiner in breeding program for developing most studied traits. On the other hand, Giza 97 exhibited negative and significant GCA effects for most studied characters, indicating that this variety is not a good combiner. Significant and positive GCA effects demonstrate the importance of genes of additive action, because they induce higher gains through selection and may be eventually fixed. Similar results were reported by Khan *et al*., (2011), Imran *et al.,* (2012), Amein *et al.,* (2013), El-Kadi *et al.,* (2013), Simon *et al*., (2013), El-Seoudy *et al*., (2014), Patel *et al*., (2014), Srinivas *et al*., (2014), Usharani *et al*., (2014), Khan *et al.,* (2015), Sultan *et al.,* (2018) and Al-Hibbiny *et al.,* (2019).

The specific combining ability (SCA) effects of each cross for the studied characters in both F_1 and F_2 generations is presented in Table (6). The results indicated that SCA effects of the crosses Giza 86 x Giza 97, Giza 92 x Giza 96 and Giza 94 x Giza 96 were positive and significant for most yield traits in both F_1 and F_2 generations.

Table 6: Specific combining ability effects of each cross for the studied characters in F_1 and F_2 generations.

Genotypes		SCY/P (g)	LCY/P (g)	B/P	L %	BW (g)
Giza 85 x Giza 86	**F_1**	4.56**	2.36**	-1.48*	0.29	0.18**
	F_2	-5.48**	-0.66	-4.00**	0.98**	0.16**
Giza 85 x Giza 92	**F_1**	6.59**	4.15**	0.80	0.89**	0.07**
	F_2	-1.19	0.80	-0.75	0.77**	0.02
Giza 85 x Giza 94	**F_1**	13.38**	5.64**	3.31**	0.24	0.03
	F_2	2.09	2.45**	2.71**	1.02**	-0.11**
Giza 85 x Giza 96	**F_1**	5.66**	1.80*	2.80**	0.12	-0.05**
	F_2	14.94**	6.93**	3.88**	0.57**	0.04*
Giza 85 x Giza 97	**F_1**	-2.86	0.09	-1.88**	0.85**	0.07**
	F_2	4.02**	1.32	-0.69	-0.23	0.11**
Giza 86 x Giza 92	**F_1**	7.69**	4.78**	1.01	1.15**	0.10**
	F_2	3.76	3.60**	-0.22	1.46**	0.12**
Giza 86 x Giza 94	**F_1**	-4.08**	-1.74*	-1.31*	0.07	0.01
	F_2	1.87	0.78	0.03	0.21	0.02
Giza 86 x Giza 96	**F_1**	10.74**	2.70**	-0.68	-0.38*	0.17**
	F_2	2.89	0.74	-1.03	-0.11	0.07**
Giza 86 x Giza 97	**F_1**	15.21**	6.84**	3.81**	0.65**	0.07**
	F_2	7.41**	2.57**	3.84**	-0.11	-0.09**
Giza 92 x Giza 94	**F_1**	-4.08*	-1.74*	-1.31*	0.07	0.01
	F_2	1.87	0.78	0.03	0.21	0.02
Giza 92 x Giza 96	**F_1**	13.46**	7.86**	5.86**	1.71**	-0.09**
	F_2	15.34**	6.27**	3.53**	0.45*	0.06*
Giza 92 x Giza 97	**F_1**	-4.69**	-2.25**	-3.12**	-0.09	0.14**
	F_2	-10.61**	-3.08**	-4.20**	0.65**	0.07**
Giza 94 x Giza 96	**F_1**	7.29**	4.17**	-0.80	0.76**	0.13**
	F_2	3.29	2.29*	-0.55	0.49**	0.06*
Giza 94 x Giza 97	**F_1**	6.16**	1.78*	1.29*	-0.01	0.05**
	F_2	6.74**	-0.46	2.74**	-1.51**	-0.03
Giza 96 x Giza 97	**F_1**	11.71**	5.60**	1.61**	-1.19**	0.11**
	F_2	27.16**	13.00**	9.72**	0.98**	-0.05*
$LSD_{0.05}$	**F_1**	**3.30**	**1.53**	**1.18**	**0.35**	**0.03**
	F_2	**3.84**	**1.76**	**1.27**	**0.38**	**0.05**
$LSD_{0.01}$	**F_1**	**4.42**	**2.05**	**1.58**	**0.46**	**0.04**
	F_2	**5.13**	**2.36**	**1.69**	**0.50**	**0.06**

*and** Significant at 0.05 and 0.01 levels of probability, respectively.

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Table 6: Continued.

Genotypes		SI (g)	2.5% SL (mm)	PI	MR	UI
Giza 85 x Giza 86	**F_1**	-0.01	0.50**	0.14**	0.01	0.77**
	F_2	0.13**	0.50**	0.08*	-0.31**	0.64**
Giza 85 x Giza 92	**F_1**	0.62**	1.08**	0.34**	-0.24**	0.51**
	F_2	0.11**	1.03**	0.27**	-0.02	0.61**
Giza 85 x Giza 94	**F_1**	-0.11*	0.64**	-0.11**	-0.08*	0.71**
	F_2	-0.11*	0.57**	-0.17**	-0.20**	0.32
Giza 85 x Giza 96	**F_1**	0.07	1.13**	0.28**	0.32**	0.37*
	F_2	-0.05	0.93**	0.22**	0.06*	0.16*
Giza 85 x Giza 97	**F_1**	-0.11*	0.02	0.02	-0.48**	0.49**
	F_2	-0.14**	0.13	-0.04	-0.01	0.66**
Giza 86 x Giza 92	**F_1**	-0.54**	0.43**	0.11**	-0.16**	0.37*
	F_2	0.24**	0.57**	0.05	-0.06*	0.11
Giza 86 x Giza 94	**F_1**	0.13*	-0.18*	0.17**	-0.14**	-0.03
	F_2	-0.04	0.45**	0.11**	-0.21**	-0.14
Giza 86 x Giza 96	**F_1**	0.54**	0.47**	0.09*	-0.26**	-0.43*
	F_2	0.48**	0.18*	0.02	0.02	0.39*
Giza 86 x Giza 97	**F_1**	0.13*	-0.40**	-0.07*	0.04	-0.41*
	F_2	0.27**	-0.26**	-0.13**	-0.19**	-0.01
Giza 92 x Giza 94	**F_1**	0.13*	-0.18*	0.17**	-0.14**	-0.03
	F_2	-0.04	0.45**	0.11**	-0.21**	-0.14
Giza 92 x Giza 96	**F_1**	-0.09	0.03	-0.22**	0.02	-0.22
	F_2	-0.23**	-0.26**	-0.28**	-0.06*	0.20
Giza 92 x Giza 97	**F_1**	0.02	-0.05	0.09*	0.14**	-0.10
	F_2	-0.02	0.07	0.03	-0.05	-0.31
Giza 94 x Giza 96	**F_1**	0.21**	-0.09	0.01	-0.04	0.31
	F_2	0.22**	0.58**	-0.05	0.02	0.71**
Giza 94 x Giza 97	**F_1**	0.03	0.31**	0.02	0.06	-0.37*
	F_2	-0.04	0.11	-0.05	0.10**	0.14
Giza 96 x Giza 97	**F_1**	0.04	0.73**	0.33**	-0.04	0.63**
	F_2	0.08	-0.06	0.27**	0.10**	0.64**
$LSD_{0.05}$	**F_1**	**0.11**	**0.13**	**0.07**	**0.07**	**0.32**
	F_2	**0.09**	**0.14**	**0.07**	**0.06**	**0.33**
$LSD_{0.01}$	**F_1**	**0.15**	**0.18**	**0.09**	**0.10**	**0.43**
	F_2	**0.12**	**0.18**	**0.09**	**0.08**	**0.44**

*and** Significant at 0.05 and 0.01 levels of probability, respectively.

On the other side, the crosses Giza 85 x Giza 86, Giza 85 x Giza 92, Giza 85 x Giza 94, Giza 85 x Giza 96, Giza 86 x Giza 92, Giza 92 x Giza 94 and Giza 96 x Giza 97 showed SCA effects for most fiber quality properties in both generations, whilst, the crosses Giza 96 x Giza 97 and Giza 86 x Giza 92 for most yield and fiber quality properties in both F_1 and F_2 generations. Similar results were reported by Khan *et al.,* (2011), Imran *et al.,* (2012), Amein *et al.,* (2013), El-Kadi *et al.,* (2013), Simon *et al.,* (2013), El-Seoudy *et al.,* (2014), Patel *et al.,* (2014), Srinivas *et al.,* (2014),Usharani *et al.,* (2014), Khan *et al.,* (2015) and Al-Hibbiny *et al.,* (2019).

3.5. Heterosis

Both desirable and useful heterosis expressed as the percentage deviations of F_1 mean performance from mid- parent (MP) and better parent, respectively for the studied characters are given

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in Table (7). B/P, 9 out of 15 studied crosses showed significant positive heterosis relative to (MP) which ranged from 2.95% for Giza 86 x Giza 96 to 14.77% for Giza 92 x Giza 96. With respect to SCY/P, 12 out of 15 crosses showed positively significant heterosis over (MP) which were ranged from 8.36% for Giza 92 x Giza 94 to 19.09% for Giza 86 x Giza 97. For lint LCY/P, the results showed that all 15 crosses were significant positive heterosis relative to (MP) which ranged from 5.49% for Giza 86 x Giza 94 to 23.76% for Giza 92 x Giza 96. In this context, four crosses were found significant positive heterosis relative to (BP) ranged from 4.47% to 9.13% for the crosses Giza 85 x Giza 86 and Giza 94 x Giza 96, respectively.

Table 7: Heterosis (%) relative to mid (MP) and better (BP) parents for the studied characters in 15 F_1 crosses.

Genotypes		SCY/P (g)	LCY/P (g)	B/P	L %	BW (g)
Giza 85 x Giza 86	**MP**	11.23*	13.91**	-0.49	3.45**	11.61**
	BP	5.09	4.47*	-1.39	1.04*	4.52**
Giza 85 x Giza 92	**MP**	12.82**	19.81**	4.67**	6.36**	7.92**
	BP	3.74	8.21**	-3.94*	4.31**	7.74**
Giza 85 x Giza 94	**MP**	14.20**	15.66**	7.54**	2.67**	6.63**
	BP	3.65	0.60	2.03	-1.30*	1.76**
Giza 85 x Giza 96	**MP**	12.31**	14.00**	9.30**	2.57**	3.00**
	BP	-3.87	-4.21	-4.57**	0.95	0.62**
Giza 85 x Giza 97	**MP**	7.03	11.63**	-1.19	3.86**	8.13**
	BP	-5.53	1.24	-13.80**	0.75	6.60**
Giza 86 x Giza 92	**MP**	13.71**	19.21**	4.02**	6.50**	9.94**
	BP	-0.71	-0.31	-3.73*	2.05**	3.11**
Giza 86 x Giza 94	**MP**	5.42	5.49**	-1.54	1.81**	6.92**
	BP	1.01	-0.48	-7.39**	0.17	4.80**
Giza 86 x Giza 96	**MP**	14.91**	14.29**	2.95*	0.82	10.91**
	BP	3.44	3.77	-10.81**	0.03	6.21**
Giza 86 x Giza 97	**MP**	19.09**	21.50**	9.79**	2.86**	9.23**
	BP	0.09	1.99	-3.47*	2.15**	3.67**
Giza 92 x Giza 94	**MP**	8.36*	8.47**	-2.46	2.26**	12.00**
	BP	-8.77	-13.42**	-14.66**	-3.51**	7.06**
Giza 92 x Giza 96	**MP**	17.04**	23.76**	14.77**	7.57**	2.52**
	BP	-6.52	-4.16	-6.83**	3.87**	0.31**
Giza 92 x Giza 97	**MP**	5.93	8.54**	-4.84**	2.16**	11.15**
	BP	1.28	8.03**	-10.01**	-2.75**	9.75**
Giza 94 x Giza 96	**MP**	11.69**	13.67**	2.26	3.11**	9.04**
	BP	4.62	9.13**	-6.35**	0.66	6.47**
Giza 94 x Giza 97	**MP**	11.26**	10.60**	3.62*	0.62	8.21**
	BP	-9.66*	-11.41**	-13.56**	-0.32	4.71**
Giza 96 x Giza 97	**MP**	16.73**	19.76**	7.51**	-2.25**	8.72**
	BP	-9.83*	-6.95**	-16.37**	-3.68**	7.72**
$LSD_{0.05}$	**MP**	**8.09**	**3.76**	**2.89**	**0.85**	**0.08**
	BP	**9.35**	**4.34**	**3.34**	**0.98**	**0.09**
$LSD_{0.01}$	**MP**	**10.83**	**5.03**	**3.87**	**1.13**	**0.10**
	BP	**12.50**	**5.81**	**4.47**	**1.31**	**0.12**

*and** Significant at 0.05 and 0.01 levels of probability, respectively.

Table 7: Continued.

Genotypes		SI (g)	2.5% SL (mm)	PI	MR	UI
Giza 85 x Giza 86	MP	1.62**	4.68**	4.06**	-5.71**	1.80**
	BP	0.19	1.08**	2.28**	-3.41**	0.38
Giza 85 x Giza 92	MP	7.72**	6.71**	5.71**	-12.45**	1.74**
	BP	6.00**	1.41**	2.49**	-2.97**	0.66
Giza 85 x Giza 94	MP	1.18**	4.86**	0.98**	-7.14**	1.99**
	BP	-0.10	0.69**	0.98**	-4.88**	1.05*
Giza 85 x Giza 96	MP	3.80**	7.49**	5.31**	5.28**	1.47**
	BP	0.48**	2.05**	0.90**	11.44**	1.06*
Giza 85 x Giza 97	MP	0.30*	3.08**	2.77**	-16.61**	1.48**
	BP	-3.39**	0.48*	1.63**	-15.88**	1.01*
Giza 86 x Giza 92	MP	-4.22**	2.82**	3.00**	-10.56**	0.81*
	BP	-7.06**	1.13**	1.57**	1.78**	0.46
Giza 86 x Giza 94	MP	2.90**	0.49**	3.09**	-8.60**	0.36
	BP	0.19	-0.09	1.33**	-8.60**	-0.12
Giza 86 x Giza 96	MP	7.88**	3.58**	2.91**	-9.66**	-0.24
	BP	3.01**	1.77**	0.27**	-1.91**	-1.23**
Giza 86 x Giza 97	MP	2.18**	-0.09	1.29**	-3.96**	-0.33
	BP	-2.92**	-1.05**	0.66**	-0.74**	-1.27**
Giza 92 x Giza 94	MP	3.44**	1.01**	1.90**	-10.56**	1.18**
	BP	3.08**	-0.08	-1.20**	1.78**	1.04*
Giza 92 x Giza 96	MP	1.47**	2.63**	0.05	-2.56**	0.23
	BP	-0.20	2.53**	-1.17**	1.78**	-0.43
Giza 92 x Giza 97	MP	0.97**	1.29**	2.68**	-1.08**	0.25
	BP	-1.20**	-1.32**	0.65**	8.61**	-0.35
Giza 94 x Giza 96	MP	5.17**	1.76**	1.55**	-3.39**	0.88*
	BP	3.08**	0.56**	-2.70**	4.90**	0.35
Giza 94 x Giza 97	MP	1.63**	1.75**	1.41**	-2.76**	-0.05
	BP	-0.89**	0.20	0.29**	0.50**	-0.51
Giza 96 x Giza 97	MP	2.70**	4.19**	5.12**	-2.86**	1.00*
	BP	2.17**	1.41**	1.80**	1.91**	0.94*
$LSD_{0.05}$	MP	**0.29**	**0.32**	**0.14**	**0.20**	**0.80**
	BP	**0.33**	**0.37**	**0.17**	**0.23**	**0.92**
$LSD_{0.01}$	MP	**0.38**	**0.43**	**0.19**	**0.27**	**1.06**
	BP	**0.44**	**0.49**	**0.22**	**0.31**	**1.23**

*and** Significant at 0.05 and 0.01 levels of probability, respectively.

For L%, results showed that 12 out of 15 crosses were significant positive heterosis relative to (MP) which ranged from 1.81% for Giza 86 x Giza 94 to 7.57% for Giza 92 x Giza 96, while five crosses showed significant positive heterosis relative to (BP) and ranged from 1.04% for Giza 85 x Giza 86 to 4.31% for Giza 85 x Giza 92. Regarding BW, the 15 studied crosses were found to be detect significant positive heterosis relative to (MP) which ranged from 2.52% to 12% for the crosses Giza 92 x Giza 96 and Giza 92 x Giza 94, respectively, while, fifteen crosses showed significant positive heterosis relative to (BP) ranged from 0.31% for Giza 92 x Giza 96 to 9.75% for Giza 92 x Giza 97. Regarding to SI, 14 out of 15 crosses showed significant positively heterosis relative to (MP) which ranged from 0.30% to 7.88% for the crosses Giza 85 x Giza 97 and Giza 86 x Giza 96, respectively, although the crosses Giza 85 x Giza 96 and Giza 85 x Giza 92 among six crosses showed significant positive heterosis relative to (BP) which ranged from 0.48% to 6%, respectively. For 2.5% SL, results demonstrated that 14 out of 15 crosses were significant positive heterosis relative to (MP) which ranged from 0.49% for Giza 86 x Giza 94 to 7.49% for Giza 85 x Giza 96, while ten crosses were significant positively heterosis relative to (BP) which ranged from 0.48% for Giza 85 x Giza 97 to 2.53% for Giza 92 x Giza 96. Regarding to PI, 14 out of 15 crosses were found to be significant positive heterosis relative to (MP) which ranged from 0.98% for Giza 85 x Giza 94 to 5.71% for Giza 85 x Giza 92, with 12 crosses which were significant positive heterosis relative to (BP) ranged from 0.27% for Giza 86 x Giza 96 to 2.49% for Giza 85 x Giza 92. On the other side, 14 out of 15 crosses were found to be significant negative heterosis relative to (MP) which ranged from -1.08% for Giza 92 x Giza 97 to -16.61% for Giza 85 x Giza 97, with seven crosses for heterosis relative to (BP) for MR. with respect to UI, 9 out of 15 crosses were significant positive heterosis relative to (MP) which ranged from 0.81% to 1.99% for crosses Giza 86 x Giza 92 and Giza 85 x Giza 94, respectively, while, five crosses were significant positive heterosis relative to (BP) which ranged from 0.94% to 1.06% for the crosses Giza 96 x Giza 97 and Giza 85 x Giza 96, respectively. Similar results were reported by Al-Hibbiny (2015), Shaker *et al*. (2016), Lingaraja *et al.* (2017) and Tigga *et al*. (2017).

3.6. Inbreedingdepression

Estimates of inbreedingdepression (I.D. %) for yield, yield components and fiber quality traits are presented inTable (8). Results demonstrated that high heterosis was generally associated with high inbreeding depression. ID% was higher in Giza 85 x Giza 86, Giza 85 x Giza 92, Giza 86 x Giza 92 for SCY/P, LCY/P, B/P and BW. Also, high inbreeding depression showed for BW and PI in most F_2 crosses as compared to other studied traits. This result suggested that dominant and over dominant genes are responsible for both BW and PI. Regarding to SI and 2.5%SL, 6 out of 15 F_2 crosses showed significant positive of inbreeding depression. On the other hand, ID% was negative and highly significant (indesirable) in seven F_2 crosses for MR. There is no inbreeding depression for UI. Similar results were reported by Khalifa (2010), Nassar (2013), Komal *et al.,* (2014), Yehia and Hassan(2015) and Mokadem *et al.* (2016).

Table 8: Inbreeding depression (%) for the studied characters in F_2 generation.

Genotypes	SCY/P (g)	LCY/P (g)	B/P	L %	BW (g)
Giza 85 x Giza 86	9.73*	7.38**	7.15**	-2.61**	2.70**
Giza 85 x Giza 92	7.58	7.39**	5.39**	-0.18	2.10**
Giza 85 x Giza 94	7.02	5.07*	-0.50	-2.06**	7.51**
Giza 85 x Giza 96	-4.32	-6.92**	-3.14	-2.45**	-1.23**
Giza 85 x Giza 97	-3.76	-1.16	-6.46**	2.48**	2.65**
Giza 86 x Giza 92	6.42	5.37*	5.03**	-1.17*	1.37**
Giza 86 x Giza 94	0.16	-0.25	-3.89*	-0.42	3.77**
Giza 86 x Giza 96	4.15	2.26	-1.02	-1.95**	5.05**
Giza 86 x Giza 97	6.08	7.70**	-3.46*	1.71**	9.26**
Giza 92 x Giza 94	-2.59	-3.04	-8.64**	-0.43	5.77**
Giza 92 x Giza 96	-1.58	0.78	1.91	2.31**	-3.69**
Giza 92 x Giza 97	4.04	2.50	-1.70	-1.62**	5.44**
Giza 94 x Giza 96	0.27	0.43	-5.10**	0.17	5.25**
Giza 94 x Giza 97	-1.35	3.01	-10.33**	4.26**	8.15**
Giza 96 x Giza 97	-10.14*	-11.06**	-20.18**	-6.23**	8.31**
$LSD_{0.05}$	**9.35**	**4.34**	**3.34**	**0.98**	**0.09**
$LSD_{0.01}$	**12.50**	**5.81**	**4.47**	**1.31**	**0.12**

*and** Significant at 0.05 and 0.01 levels of probability, respectively.

Table 8: Continued.

Genotypes	SI (g)	2.5% SL (mm)	PI	MR	UI
Giza 85 x Giza 86	-2.07**	-0.29	2.04**	9.60**	0.07
Giza 85 x Giza 92	5.94**	0.56**	1.98**	-5.50**	0.05
Giza 85 x Giza 94	2.13**	-0.17	2.14**	4.62**	0.51
Giza 85 x Giza 96	2.99**	1.29**	1.96**	5.87**	-0.03
Giza 85 x Giza 97	1.50**	0.30	2.08**	-15.63**	-0.31
Giza 86 x Giza 92	-10.02**	-0.56**	2.00**	-0.58**	0.11
Giza 86 x Giza 94	0.47**	-2.80**	2.06**	4.58**	-0.15
Giza 86 x Giza 96	-0.73**	1.02**	1.89**	-6.94**	-1.60**
Giza 86 x Giza 97	-3.49**	-0.38*	2.08**	5.50**	-0.93*
Giza 92 x Giza 94	2.41**	0.56**	2.06**	7.29**	0.08
Giza 92 x Giza 96	2.10**	1.65**	2.01**	2.33**	-0.90
Giza 92 x Giza 97	0.51**	0.37*	2.02**	4.37**	0.00
Giza 94 x Giza 96	1.45**	-1.76**	2.04**	-0.78**	-0.96*
Giza 94 x Giza 97	1.50**	0.49*	2.01**	-1.23**	-0.93*
Giza 96 x Giza 97	0.10	3.24**	1.95**	-6.15**	-0.70
$LSD_{0.05}$	**0.32**	**0.37**	**0.19**	**0.20**	**0.91**
$LSD_{0.01}$	**0.43**	**0.50**	**0.26**	**0.27**	**1.22**

*and** Significant at 0.05 and 0.01 levels of probability, respectively.

3.7 Genetic parameters

Knowledge of gene action aids in the optimal selection of parents for hybridization, as well as the selection of appropriate breeding programs for genetic improvement of specific quantitative traits. As a result, the plant breeder must understand the nature of gene action involved in the development of the many quantitative traits before beginning a prudent breeding program. The estimates of variance components of combining ability for the studied characters in F_1 and F_2 generations presented in Table (9). The results indicated that the additive genetic variance was higher as compared with non-additive genetic variance in both F_1 and F_2 for B/P, SCY/P, LCY/P and PI in both F_1 and F_2, indicating that additive effects play a major role in the expression of these traits. Similar results were reported by **Abd El-Zaher *et al.* (2009), Basal *et al.* (2009), Khalifa (2010), El-Kadi *et al.* (2011), Jenkins *et al.*(2012), Saleh and Ali (2012), Linga swamy *et al*., (2013), Nassar (2013), Deore *et al.,* (2014), El-Seoudy *et al.* (2014), Kaleri *et al.* (2015)** and **Chapara *et al.* (2020).**

Table 9: Estimates of variance components of combining ability for the studied characters in F_1 and F_2 generations.

variance components		SCY/P (g)	LCY/P (g)	B/P	L %	BW (g)
σ^2_{GCA}	**F_1**	458.19	80.09	37.58	0.23	0.01
	F_2	500.25	90.55	41.08	0.16	0.01
σ^2_{SCA}	**F_1**	168.59	37.33	6.72	0.83	0.03
	F_2	197.67	40.77	18.05	1.03	0.01
$\sigma^2_{GCA}/\sigma^2_{SCA}$	**F_1**	2.72	2.15	5.59	0.28	0.33
	F_2	2.53	2.22	2.28	0.16	1.00
σ^2_A	**F_1**	916.38	160.18	75.16	0.46	0.02
	F_2	1000.50	181.09	82.16	0.32	0.01
σ^2_D	**F_1**	168.59	37.33	6.72	0.83	0.03
	F_2	197.67	40.77	18.05	1.03	0.01

Table 9: Continued.

Variance components		SI (g)	2.5% SL (mm)	PI	MR	UI
σ^2_{GCA}	F_1	0.03	0.28	0.03	0.02	0.10
	F_2	0.06	0.26	0.04	0.02	0.05
σ^2_{SCA}	F_1	0.08	0.60	0.05	0.05	0.16
	F_2	0.05	0.51	0.02	0.05	0.33
$\sigma^2_{GCA}/\sigma^2_{SCA}$	F_1	0.38	0.47	0.60	0.40	0.63
	F_2	1.20	0.51	2.00	0.40	0.15
σ^2_{A}	F_1	0.06	0.57	0.06	0.05	0.32
	F_2	0.12	0.53	0.07	0.05	0.11
σ^2_{D}	F_1	0.08	0.60	0.05	0.05	0.10
	F_2	0.05	0.51	0.02	0.05	0.33

4. Conclusions

Giza 86 and Giza 94 were the best general combiners for yielding traits, whereas Giza 92 and Giza 96 were the better general combiners for fiber traits in both F_1 and F_2 generations.

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